SUSTAINABLE WATER USE SECURING FOOD PRODUCTION IN DRY AREAS OF THE MEDITERRANEAN REGION (SWUP-MED) PROJECT

WP3b: AGRONOMY TO COUNTERACT SALINITY

Deliverible 3a.2 Determination of the potential of the use and avialability of marginal qaulity water resources and selection of appropriate water harvesting techniques in the different pedo-climatic conditions

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Potential of Use and Availability of Marginal-quality Water Resources

Introduction

Whenever good quality water is scarce, water of inferior quality will have to be considered for use in agriculture, irrigation of lawns and gardens, washing of pavements, and other uses not requiring high quality water. Inferior quality water is also designated as non-conventional water or marginal quality water. Non-conventional water can be defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose (Pescod, 1992). Thus, the use of non-conventional water requires adoption of more complex management practices and more stringent monitoring procedures than when good quality water is used.

Non-conventional waters most commonly include saline water, brackish water, agricultural drainage water, water containing toxic elements and sediments, as well as treated or untreated wastewater effluents. All these are waters of inferior or marginal quality. Also included under the designation of non-conventional waters are the desalinated water and water obtained by fog capturing, weather modification, and rainwater harvesting. The expansion of urban populations and the increased population served by domestic water supply and sewerage give rise to greater quantities of municipal wastewater. With the current emphasis on environmental health and water pollution issues, there is an increasing awareness of the need to dispose of these wastewaters safely and beneficially. The use of wastewater in agriculture is already expanding, particularly in water scarcity regions. However, the quantity of wastewater available in most countries will account for only a small fraction of the total irrigation water requirements. Nevertheless, wastewater use will result in the conservation of higher quality water and its use for purposes other than irrigation. The nitrogen and phosphorus content of sewage might reduce the requirements for commercial fertilisers. As the marginal cost of alternative supplies of good quality water will usually be higher in water scarce areas, it is important to incorporate agricultural reuse into water resources and land use planning.

Reuse of treated water for non-agricultural uses is quite small relative to irrigation of agricultural crops. These applications include the reuse of treated industrial effluents for low quality uses in the same industrial plant, the reuse of treated municipal wastewater in aquaculture, for the irrigation of lawns and recreational areas, and for low quality domestic water uses when separated (dual) municipal distribution systems are available. The increase in food production for the continuously growing world population will have to be met in large proportion by expansion of irrigation. In water scarce regions, irrigation has the ability not only to increase production per unit area of land but also to stabilise production. In arid and semi-arid areas, irrigation is the only reliable means of increasing agricultural production on a sustainable basis. However, good quality water for irrigation is increasingly short since a number of countries are approaching full utilisation of their water resources and priority is being given to uses requiring higher quality water. Therefore water of inferior quality produced from saline aquifers or resulting from drainage waters has to be used/reused for irrigation of agricultural crops along with wastewaters. In case of reuse of drainage waters, agriculture acts both as an utiliser of the water and as a disposal site, so contributing to control of potential environmental impacts from salts carried by those waters.

As for treated effluents, saline water may also be used for non-agricultural purposes such as washing, low quality domestic uses or irrigation of recreational areas. However, the use of saline waters in irrigation has positive impacts for non-agricultural uses because it decreases their demand for good quality water, and the good quality water then becomes available for uses requiring more stringent water quality standards.

Desalinated waters are commonly added to the fresh waters for domestic uses. They are free from toxic substances or pathogens and can, therefore be used to satisfy most human requirements. By contrast, because of its low level of salts and the high costs associated with treatment, desalinised water is less appropriate for agricultural uses.

Wastewater use

Municipal wastewater is mainly comprised of water with relatively small concentrations of suspended and dissolved organic and inorganic solids. Organic substances include carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. In arid and semi-arid countries, water use is often fairly low and sewage tends to be very strong.

Wastewaters characteristics relative to agricultural use

The quality of irrigation water is of particular importance in arid zones where high rates of evaporation occur, with consequent salt accumulation in the soil profile. The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when effluent use is being planned, several factors related to soil properties must be considered. Ayers and Westcot (1985) provide appropriate recommendations on these water quality aspects. Another aspect of agricultural concern is the effect of dissolved solids (TDS) in irrigation water on the growth of plants. Dissolved salts increase the osmotic potential of soil water and therefore increase the amount of energy which plants must expend to extract water from the soil. As a result, growth and yield of most plants decline progressively as osmotic pressure increases due to the presence of salts in the soil and the soil water. Many of the ions carried in the wastewaters are harmless or beneficial at relatively low concentrations, but may become phytotoxic at high concentrations, or may negativelyaffect several metabolic processes.

Important agricultural water quality parameters include a number of specific properties of water that are relevant in relation to the yield and quality of crops, maintenance of soil productivity and protection of the environment. These are analysed in the next section. These parameters mainly consist of certain physical and chemical characteristics of the water, such as (Pescod, 1992; Kandiah, 1990; Rhoades *et al.*, 1992):

- Total salt concentration or the total dissolved solids, because the salinity of the soil is directly affected by the salinity of the irrigation water.
- Electrical conductivity, which is used to indicate the total ionised constituents of water and is closely correlated with the total salt concentration.
- Sodium adsorption ratio (SAR), because when sodium is present in the soil in exchangeable form, it causes adverse physico-chemical changes, particularly to soil structure.

Due to the ability of sodium to disperse the soil aggregates, a crust is formed on the soil surface reducing the infiltration rates and affecting germination and seedling emergence. The SAR is defined by the ionic ratio. If significant precipitation or dissolution of calcium due to the effect of carbon dioxide (CO2), bicarbonate (HCO3-) and total salinity of the water (ECw) is suspected, the adjusted sodium adsorption ratio (SARadj) can be used as reported by Ayers and Westcot (1985).

- Toxic ions. When at concentrations above threshold values, they can cause plant toxicity problems, which affect growth and yield of crops. The degree of damage depends on the crop, its stage of growth, and the concentration of the ions. The most common phytotoxic ions in municipal sewage and treated effluents are boron (B), chloride (C1), and sodium (Na).
- Trace elements. Attention should be paid to trace elements in sewage effluents if industrial wastewater is included. The main ones are Aluminium (Al), Beryllium (Be), Cobalt (Co), Fluoride (F), Iron (Fe), Lithium (Li), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Tin (Sn), Titanium (Ti), Tungsten (W) and Vanadium (V).
- Heavy metals, a special group of trace elements, which have been shown to cause health hazards when taken up by plants: Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg) and Zinc (Zn).
- pH. The normal pH range for irrigation water is from 6.5 to 8.4. pH values outside this range indicate water is abnormal in quality. The salt accumulation in the root zone is generally controlled by leaching of the salts from the root zone naturally when rainfall is abundant, or by applying a leaching fraction with the irrigation water. Leaching with the irrigation water is carefully dealt with by Rhoades *et al.* (1992).

The appropriate application of a leaching fraction depends on the irrigation method and the performance of the irrigation system. Practising over-irrigation to be sure that salts are leached down from the root zone is common but this produces excessive percolation to the groundwater. The groundwater then rises close to the soil surface, and the groundwater quality can be degraded. Therefore, to avoid problems due to deep percolation, drainage has to be considered. However, problems may be controlled easily if the irrigation system is designed carefully allowing for control of volumes applied and for an even distribution of water over the field.

Summarising, the safe use of wastewater in irrigation requires not only compliance with guidelines for the control of health risks, but also well designed and efficient irrigation systems. Case study examples are provided in the literature (e.g. Oron *et al*., 1999, Loudon, 2001; Ragab *et al*., 2001).

Monitoring and control for safe wastewater use in irrigation

Developing a program to promote safe crop production areas should occur alongside and as an alternative to crop restrictions. This can be achieved with a three-phased process (see Westcot, 1997). The first phase is to develop a sound water quality monitoring program that is used to evaluate the existing levels of contamination in the water being used. This includes selection of contamination indicators, establishing field-sampling methods, defining laboratory methods and participating laboratories, selecting field monitoring sites, and then conducting a field water quality monitoring program. The second phase consists of evaluating the water quality data and developing procedures to assess the levels of contamination. The resulting database can be used to define safe production areas and as a basis to control or regulate contaminated water use in vegetable or other high-risk areas. The third phase is developing mechanisms to regulate the use of potentially contaminated water on high-risks crops, so leading to certification programs.

(a) *Monitoring and development of an information database.*

The goal of a water quality monitoring program is to determine spatially how extensive is the contamination of irrigation water and at what level. Results must provide the Authorities with a sound basis for any required follow-up action. The procedure and parameters used for measurement must have national and international recognition and be applicable to the entire country. The following steps should be considered:

1. Selection of observation areas and sites. This may be performed by considering:
   - The availability of data on water quality and water vector diseases.
   - The location of major vegetable and high-risk crop production areas.
   - The location of major population centres near vegetable production areas, namely those located upstream of vegetable production areas or inside the irrigated area.
   - The availability of information characterising the irrigation system and its operation and management.
   - The irrigation methods and crop production practices used in various production regions of the country.
   - The location and capacity of laboratory facilities.
   - Resources available for conducting the sampling and laboratory analyses.
2. Selection of the water quality indicators, which should be:
   - Not disease specific but applicable to several diseases; indicators include those for helminth eggs and bacteria, namely the faecal coliform.
   - Recognised at national and international levels.

- Used for routine testing and using analytical procedures well known in national laboratories.
- Able to provide a basis for establishing guidelines and regulations.

3. Choice of analytical methods, which should be reliable, cost effective and well known from national laboratories, and have international acceptance.
4. Selection of laboratories, in terms of certified quality, knowledge on procedures to be used, and distance to the monitored areas.
5. Selection of sampling techniques, including number and frequency of samples, which depend upon the objectives of monitoring indicators selected, and resources available.
6. Selection of field sites. These depend upon:
    - Water sources in the irrigated area.
    - Location of contaminant inputs, - occurring prior to the canal supply or within the irrigation system (primary and secondary contamination, respectively).
    - Crop patterns and cropping and irrigation practices.

(b) *Data assembling and implementation of a database*. Consideration should be given to existing data - geographical, physical, agronomic, irrigation, health and water quality data - as well as to sampling methods, analytical procedures and indicators to be included in the monitoring program.

(c) *Certification, regulation and other policy issues.*

1. Certification may be considered for the quality of products and for the safety of production, which stimulates optimal practices by the farmers.
2. Similarly, when water quality reaches a level where health hazards are not to be expected, certification can be given to the quality of the water.
3. Certification may be given to an irrigated area where standards are met, or to individual farmers.
4. Policy issues include:
    - Benefits associated with certification.
    - Regulations aiming at control of specified contaminants, promotion of improved health standards and irrigation practices.
    - Policies on long-term wastewater use.

Waste Water Potential

Based on estimates by the Food and Agriculture Organization of the United Nations (FAO AQUASTAT), the volume of wastewater generated by the domestic and industrial sectors in the different Middle East and North Africa countries is shown in Table 1. Qadir et al. (2009) have reported that the ratio by volume of treated wastewater to that generated in the Arab region (54%) “is higher than Asia (35%), Latin American/Caribbean (14%), and Africa (1%).

Country	Total water withdrawal (10^9 m^3/year)	Total wastewater produced	Volume of Treated Wastewater
Algeria	6.070 (2000)	0.8200 (2002)	-
Egypt	68.300 (2000)	3.7600 (2001)	2.9710 (2001)
United Arab Emirates	3.998 (2005)	0.5000 (1995)	0.2890 (2006)
Iraq	66.000 (2000)	-	-
Libya	4.326 (2000)	0.5460 (1999)	0.0400 (1999)
Jordan	0.941 (2005)	0.0820 (2000)	0.1074 (2005)
Lebanon	1.310 (2005)	0.3100 (2001)	0.0040 (2006)
Morocco	12.600 (2000)	0.6500 (2002)	0.0400 (1999)
Syria	16.700 (2003)	1.3640 (2002)	0.5500 (2002)
Palestine	0.418 (2005)	-	-
Tunisia	2.850 (2001)	0.1870 (2001)	0.2150 (2006)
Turkey	41,000(2010)	3,7500 (2010)	2.7000 (2010)

FAO AQUASTAT Database. Global information system on water and agriculture. http://www.fao.org/nr/water/aquastat/main/index.stm [Accessed 15 May, 2010].

Use of brackish, saline and drainage waters

Saline water includes water commonly called brackish, saline or hyper-saline from different sources, including aquifers which are naturally saline or became saline due to human activities, and drainage effluents from agricultural land. It also includes water that contains one or more specific elements in concentrations above those found in good quality water. Fresh water is considered to have a total dissolved solids (TDS) concentration of less than 500 mg/l (EC < 0.7 dS/m). Saline and brackish water have 500 to 30 000 mg/l (0.7 to 42 dS/m) TDS, while sea water has TDS averaging 35 000 mg/l (49 dS/m).

The use of saline drainage water in Egypt is above 5 billion m3 for irrigating nearly 500 000 ha of land. Drainage water is used in many parts of the world including California, USA. Saline groundwater is used extensively in many countries such as Tunisia, India, and Israel. Reports on use of saline water are abundant in the literature (e.g. Kandiah, 1990, Rhoades *et al.*, 1992; Tyagi and Minhas, 1998, Gupta *et al.*, 1998). The use of highly saline waters, unusable by common agricultural crops, may be feasible for halophytes, which could be explored for human and animal consumption (Choukr-Allah *et al.*, 1996; Hamdy and Lieth, 1999).

Waterlogging, salinity and related problems have arisen in many irrigation areas where fresh water is used for irrigation. Such problems could arise even more quickly and more severely when saline water is used. The major potential hazards associated with the use of saline water in agriculture are (Ayers and Westcot, 1985, Kandiah, 1990):

(a) *Yields decrease* due to:

1. Reduced soil water availability to the crop.

2. Reduced soil infiltration rates to such an extent that sufficient water cannot infiltrate to supply the crop adequately.

3. Soil crusting, affecting infiltration of water and crop emergence.

4. Toxicity to the crop when the concentration of certain ions is high enough to cause crop damage and to reduce yields.

5. Imbalance of nutrients available to crops, caused by excess concentrations of certain ions or the prevention of crop uptake of others.

(b) *Soil degradation* up to the point of making it unproductive due to:

1. Salinisation: when saline water is used inappropriately, particularly in the absence of adequate leaching and drainage, salts accumulate in the root zone and in the groundwater from where they rise to the soil surface, so the soil becomes saline.

2. Sodification: when the composition of salts in the saline water is such that there is a relatively high sodium content as compared to other cations, then the soil complex accumulates this excess sodium. When soils become sodic, they lose their structure and tilth, become dispersive and have reduced infiltration rates and permeability.

3. Loss of soil productivity: when the processes of salinisation and or sodification are continued, conditions for plants to extract water and nutrients become progressively worse and soil productivity decreases to levels where crop production is no longer feasible.

(c) The *effects on the environment* are related to specific ions transported in the water, namely, nutrients and toxic elements. Effects include: 1. Soil degradation as referred above, which is an environmental damage by itself and contributes to desertification.

2. Damages to the soil environment, causing negative changes in plant communities which hampers animal life and soil biodiversity.

3. Nutrients in reused drainage effluents give rise to uncontrolled algal blooms, and to heavy development of aquatic weeds in irrigation canals and other water bodies where they discharge. Those lead to clogging problems in hydraulic structures and equipment, in waterways and canals, and reduce the wild life which inhabit farm ponds, lakes and reservoirs.

4. When nitrogen in reused drainage waters is excessive or when it is not taken into consideration in the fertilisers' balance, the resulting excess nitrates add to groundwater pollution.

5. The presence of particular ions to levels exceeding specific health and safety thresholds affect either plants sensitive to those ion concentrations, or animals that drink those waters. A typical case is the presence of selenium in drainage waters in California, which affects certain bird communities, with consequences for the whole of the environmental chain in which they play a part.

(d) The *risk for public health* result from:

1. The presence of toxic ions such as the heavy metals that, although they may be present in minute concentrations, are cancerous when accumulated in humans.

2. Some vectors of disease, such as mosquitoes and snails, which develop better in saline waters, mainly those rich in nutrients, so creating or increasing health hazards for the populations living in areas using saline water or reusing drainage waters.

The negative impacts which result from the use of saline waters can be overcome when water management is performed appropriately, that is having the control of the negative impacts as a main goal. However, this implies good knowledge of the mechanisms influencing plant stress and soil degradation, and appropriate information on the quality characteristics of the waters being used and of the toxic ions, nutrients or disease vectors likely to be present. Only when such information is available will it be possible to select the crops, cultivation techniques, irrigation methods and water management practices that facilitate saline water use. An FAO expert consultation (Kandiah, 1990) revised the recommendations for use of saline water for irrigation. These include the need for:

- Integrated management of water of different qualities at the levels of the farm, the irrigation system and the drainage basin when sustaining long-term production potential of land and water resources is a main goal.
- Adopting irrigation methods with high performance, using minimal leaching fractions to reduce drainage volumes, implementing reuse of drainage water for progressively more tolerant crops, and reusing otherwise unusable saline water for halophyte production.
- Monitoring of soil and water quality, providing feedback to management to provide for optimal operation and control of the irrigation systems. Further development in understanding the effects of saline irrigation water on soilplant- water relationships, including cumulative effects on perennials.
- Promotion of tools to predict long and short-term effects of irrigation water quality on crop yields, soil properties and quality of the environment.
- Establishment of pilot areas to test and assess irrigation methods and complementary soil and crop management practices for using saline water.
- Training of irrigation and agricultural officers.

Criteria and standards for assessing the suitability of water for irrigation

A great deal of research on the water quality requirements for irrigation has been developed over a long time. Consolidated standards have been made available, namely by FAO (Ayers and Westcot, 1985; Kandiah, 1990; Rhoades *et al.*, 1992). It is then possible to define the main water quality parameters which must be known to allow saline waters to be used safely in irrigation.

Recommendations by FAO include:

(a) Water quality characteristics to be considered for irrigation to assess the suitability of saline water concerning, particularly:

- Salinity hazards (total dissolved salts, TDS and electrical conductivity, EC).
- Crusting and permeability hazards (SAR or SARadj (also renamed RSC), EC, and pH).
- Specific ion toxicity hazard (Na, Cl, B, and Se, among others).
- Nutrient imbalance hazard (excess NO3, limited Ca, phosphate, etc.).

(b) Parameters required to evaluate the quality of saline water on a routine basis include: TDS, EC, concentration of cations and anions (mainly Ca, Mg, Na, CO3, HCO3, Cl, SO4), SAR or the adjusted SAR (or RSC) under certain conditions, trace elements (such as Se, As, B, Mo, Cd, Cr, Cu), as well as other potentially toxic substances of agricultural origin.

(c) Water quality standards already available should be evaluated through research and adjusted for the specific conditions of saline water use, including soils, climate, crops and crop sequences, and irrigation methods. More emphasis should be given to the development of appropriate models, criteria and standards applicable under nonsteady conditions.

(d) Guidelines on use of saline water should also include the possible hazardous effects of trace elements on people or livestock which consume crops produced using such water (As, Se, etc.).

Crop irrigation management using saline water

Water for agricultural use is normally considered to be in one of five salinity classes. These classes and their boundaries being defined by the total dissolved solids and electrical conductivity of the water. Crop responses to salinity vary with crop species and, to a lesser degree, with the crop variety. The tolerance of crops to salinity is generally classified into four to six groups, from the sensitive (or non tolerant), where most horticultural and fruit crops are included, to the tolerant, which includes barley, cotton, jojoba, sugarbeet, several grass crops, asparagus and date palm. Full lists of crop tolerance classes are given by Ayers and Westcot (1985) and Rhoades *et al.* (1992) among others. The behaviour of various crops under irrigation with water of different degrees of salinity varies with species, varieties and the crop growth stages. As irrigation water salinity increases, germination is delayed. Germination is adversely affected for most field crops when the EC of the irrigation water or the soil saturation extract reaches a threshold of 2.4 dS/m. Adverse effects occur at lower values (< 1 dS/m) for non-tolerant crops, and at higher values for tolerant crops (generally not exceeding 4 dS/m). The germination and seedling stages are the most sensitive to saline water irrigation. Any adverse effects at such stages will lead to a reduction in crop production proportional to the degree of plant loss during germination and plant establishment. At this stage, water of good quality should be used, especially if plants are sensitive. If fresh water is lacking at this stage, irrigation during seedling development, after germination must be carried out with fresh water to avoid dramatic effects on yields (Hamdy, 1996). Besides germination and crop establishment, another growth stage where most crops are more sensitive to salinity is the reproductive phase. Other critical stages vary from crop to crop. Several case studies are reported in the literature (e.g. Hamdy, 1994; Hamdy and Karajeh, 1999). The suitability of water for irrigation based on salinity, leaching and drainage requirements, and crop tolerance to salinity must be related to irrigation management.

Several approaches can be adopted in water and crop management to minimise the accumulation of salts in the active root zone and to eliminate salt stress, especially during the critical growing stages of the plants. These include:

- Appropriate selection of irrigation methods.

- Efficient leaching management, including volumes and frequency, and respective drainage of the salty water away from the cropped land.
- Proper irrigation scheduling, in agreement with the available irrigation system.
- Crop rotations adapted to the prevailing conditions. Considerations must include irrigation water quality, soil salinity levels, chemical and physical properties of the soils, and climatic conditions.

The selection of the irrigation method must consider the quality of the water and the potential for both the water and the irrigation method to produce negative impacts. These refer to the capabilities for controlling:

- soil salinity hazards due to salt accumulation in the root zone,
- toxicity hazards caused by direct contact of the salty water with the plant leaves and fruits,
- soil infiltration and permeability hazards caused by the modification of the soil physical properties, mainly due to the Na ion, and
- yield hazards which may occur when the irrigation system does not allow adoption of appropriate irrigation management, the frequency and volumes of irrigation.

One of the most important factors in crop management when using saline irrigation is the irrigation frequency. Saline water requires more frequent irrigation than for fresh water because salts in the water and the soil increase the osmotic potential of the soil water, which makes water uptake by the crop roots more difficult. However, increasing the frequency implies reducing the depth of water applied at each irrigation to avoid gross accumulation of salts in the soil. The irrigation application depths that can be used depend on the irrigation method and the off-farm system delivering water to the fields.

Surface irrigation methods make it extremely difficult to apply small irrigation depths. When water is delivered to the farms through surface canal systems, the delivery schedules are generally of the rotation type, and are rigid, delivering large irrigation volumes at long intervals. These systems are inappropriate for irrigation of less tolerant crops. A methodology for estimating salinity impacts on crop yields is proposed by Rhoades *et al.* (1992), and Allen *et al.* (1998) propose a method for estimating crop water requirements under salinity conditions. These methods rely on knowledge of the threshold ECe at which crops are affected, and the rate of yield decrease when the salinity of the irrigation water increases by 1 dS/m. These values are tabulated in both quoted publications. The ECe threshold ranges from 1.0 dS/m for very sensitive crops such as carrots and beans up to more than 7.5 dS/m for barley, cotton, and tolerant grasses. The rate of decrease in yield per unit increase in EC varies from more than 15 % (dS/m) for the sensitive crops down to 5 % (dS/m) for tolerant crops.

Several strategies are usually adopted to facilitate irrigation with saline water, as reported by Kandiah, 1990; Gupta *et al.*, 1995; Hamdy and Karajeh, 1999 among others. Mainly the strategies consist of:

(a) The *dual rotation* management strategy (Rhoades, 1990), in which sensitive crops (e.g. lettuce, alfalfa) in the rotation are irrigated with low salinity river water, and salt-tolerant crops (e.g. cotton, sugarbeet, wheat, barley) are irrigated with saline drainage water. For the tolerant crops, the switch to drainage water is usually made after seedling establishment, i.e. irrigations at pre-planting and at the initial crop stages are made with low salinity water. Benefits from this strategy include (Rhoades, 1990): (i) harmful levels of soil salinity in the root zone do not occur because saline water is used only for a fraction of the time; (ii) substantial alleviation of salt build-up in the soil occurs during the time when salt-sensitive crops are irrigated with fresh water; (iii) proper pre-planting irrigation and careful irrigation management during germination and seedling establishment leach salts out of the seed layer and from shallow soil depths. The main difficulties with this strategy are the complexity of water management for farmers and system mangers and the possible lack of fresh water when it is required.

(b) *Blending*, which is a drainage reuse strategy where water supplies of different salinity levels are mixed in variable proportions before or during irrigation (Shalhevet, 1994; Rhoades, 1990, Tyagi, 1996). Irrigation water having a quality superior to that of the saline water and able to satisfy the allowed salinity threshold for the crops to be irrigated is obtained. Blending may be more practical and appropriate on large farms because it is practised by the farmer himself, taking into consideration the crops grown and the respective growth stages. On the other hand, in large irrigation systems supplying many small farms it would be difficult to properly satisfy the requirements of all the crops to be grown, unless a cropping pattern was imposed for all farms.

(c) *Cyclic application* of saline and fresh water (Tyagi, 1996). Salinity must not be above acceptable thresholds for the crops grown. Cycles of application of fresh water should coincide with the more sensitive growth stages, particularly for planting and seedling development, and for the leaching of the upper soil layers. This strategy has more potential and flexibility than the blending strategy and may be easier to implement.

Monitoring and evaluation

Most studies indicated that using irrigation water containing salts in excess of conventional suitability standards, can be successful on numerous crops for at least seven years without a loss in yield (Rhoades, 1990). However, uncertainty exists concerning the long-term effects of these irrigation practices on the physical quality of the soil. These effects largely depend on the soil chemical and physical characteristics, on the climate and on the possibility of leaching with natural rain or using higher quality water for leaching as mentioned above. The greatest concern with regard to long-term reuse of drainage water for irrigation is its effects on the soil physical quality, particularly the reduction of water infiltration capacity. According to Rhoades (1990), this is especially important where reuse is practised on poorly structured soils and the drainage water has SAR > 15 (mmol/l)½. The capability to predict changes in soil infiltration and permeability is still beyond current knowledge of soil physics. Long-term effects on soil salinisation are already considered when using simulation models. However existing knowledge is quite limited. Soil variability in space and irrigation variability both in time and space produce large uncertainty in predictions. For instance, soil salinity under a cyclic strategy of application will fluctuate more, both spatially and temporally, than if using a blending strategy. Therefore, predicting or anticipating plant response would be more difficult under the former. Nevertheless, management schemes must be practised that keep the average root zone salinity levels within acceptable limits in both strategies.

Drainage water often contains certain elements, such as boron and chloride, that can accumulate in plants to levels that cause foliar injury and a subsequent reduction in yield. This is another cause of uncertainty and, in many cases, this may produce more long-term detrimental effects than salinity. Another long-term consideration with regard to reuse of drainage water is the potential for accumulation of heavy metals in plants and soils. These metals can be toxic to human and animal consumers of the crops. For these cases also, there is only limited potential for using prediction models to estimate when long term impacts would be important.

Monitoring soil salinity, leaching and drainage adequacy is therefore required to evaluate the long term impacts from using saline waters, irrespective of whether the source of the saline water is groundwater or drainage water. Monitoring and evaluation should be concerned with:

- The status of salts throughout the soil profile on a continuous basis, with the aim of detecting changes in salinity levels and identify when salt build up is steadily increasing.
- The functioning and performance of the drainage system, including observations of the hydraulic head, drainage outflows and salts transported with the drainage water.
- The irrigation performance, not only to observe the irrigation efficiency but also the uniformity of water distribution and the leaching fractions actually applied.
- The irrigation schedule in respect to the satisfaction of irrigation and leaching requirements, and the constraints on delivery or other restrictions that may hamper the appropriate irrigation management.
- Sampling EC throughout the irrigated area to identify the occurrence of problem areas requiring specific care in water management.
- Sampling for specific ions that may be present in the irrigation water and that could have specific toxicity effects or, as for heavy metals, could create health risks.
- Follow-up non agricultural impacts from using saline water, such as changes in groundwater quality, in plant ecosystems and in wetland or river-bed fauna and flora.

Traditional laboratory techniques of salinity measurement using soil samples are impractical for the inventory and monitoring requirements of large areas, so new approaches have recently been developed, particularly those described by Rhoades et al. (1999) that were developed especially for application in large areas. Environmental impact assessment methodologies for irrigation and drainage projects (Dougherty and Hall, 1995) may also be adapted for surveying and monitoring areas where water of inferior quality, i.e. saline and wastewater, is used for irrigation.

Pescod, 1992

b. Selection of Appropriate Water Harvesting Techniques in Different Pedo-Climatic Conditions

The Concept

Water harvesting has been defined in several ways. Here we consider it in the broadest sense, as an umbrella term covering a wide range of techniques and methodologies to collect and conserve various forms of runoff water, originating from ephemeral water flows generated during tropical rainstorms. In this sense we adopt a similar approach as the definition by Siegert (1994) of water harvesting as "the collection of water for its productive use". Water harvesting focuses on improving the productive use of rainwater on the local scale (field to sub-catchment scale) before the runoff water leaves the geographical unit in question. The aim is to mitigate the effects of temporal water shortages to cover both domestic and agricultural needs. In terms of upgrading rainfed agriculture, water harvesting can be categorised according to three broad objectives:

1) Systems that improve infiltration of rainwater into the soil.
2) Systems that prolong the duration of soil moisture availability in the soil.
3) Systems that store surface and sub-surface runoff for later use.

Water harvesting incorporates a broad set of techniques and methodologies that can be grouped in three main domains:

1) In-situ moisture conservation (soil and water conservation, SWC).
2) Concentration of runoff to crops in the field, on field scale (runoff farming) or on catchment scale (flood water harvesting).
3) Collection and storage of runoff water in different structures (soil, ponds, dams, tanks) for supplemental irrigation.

There is no generally accepted definition of water harvesting. The definition used in this paper covers "the collection of runoff and its use for the irrigation of crops, pastures and trees, and for livestock consumption" (Finkel and Finkel 1986). Water harvesting (WH), defined as "the collection of water for its productive use" (Siegert, 1994; Rockström, 2002), has supported subsistence farming in the arid and semi-arid regions of the world for a long time and proved to be one of the most promising methods of making water available for crop growth in arid and semi-arid areas (Ouessar et al. , 2004; Fleskens et al. , 2005).

The goals of water harvesting are:

- Restoring the productivity of land which suffers from inadequate rainfall.
- Increasing yields of rainfed farming
- Minimizing the risk in drought prone areas
- Combating desertification by tree cultivation
- Supplying drinking water for animals.

In regions with an annual precipitation between 100 and 700 mm, low cost water harvesting might provide an interesting alternative if irrigation water from other sources is not readily available or too costly. (In summer rainfall areas the minimum precipitation for water harvesting is around 200 mm/year). In areas with more than 600 - 700 mm annual rainfall water harvesting techniques can prolong the cropping season. In comparison with pumping water, water harvesting saves energy and maintenance costs. These advantages are countered by the problem of unreliability of rainfall, which can partly be overcome by interim storage (cisterns, small reservoirs etc.). Modern hydrological tools (e.g. calculation of rainfall probability and water yield) allow a more precise determination of the necessary size of the catchment area.

Basic Concepts and Characterization of Water Harvesting

Water harvesting is applied in arid and semi-arid regions where rainfall is either not sufficient to sustain a good crop and pasture growth or where, due to the erratic nature of precipitation, the risk of crop failure is very high. Water harvesting can significantly increase plant production in drought prone areas by concentrating the rainfall/runoff in parts of the total area. The intermittent character of rainfall and runoff and the ephemerality of floodwater flow requires some kind of storage. There might be some kind of interim storage in tanks, cisterns or reservoirs or soil itself serves as a reservoir for a certain period of time (Finkel and Finkel 1986).

Water harvesting is based on the utilisation of surface runoff; therefore it requires runoff producing and runoff receiving areas. In most cases, with the exception of floodwater harvesting from far away catchments, water harvesting utilizes the rainfall from the same location or region. It does not include its conveyance over long distances or its use after enriching the groundwater reservoir. Water harvesting projects are generally local and small scale projects (Prinz, 2004).

Water Harvesting Techniques:

The conventional irrigation methods use the rainfall after it has infiltrated into the ground, using underground water or the water of permanent streams and rivers. The methods, which are described in this chapter, collect the rainfall before it enters the soil, i. e. as surface runoff /overland flow (Prinz, 2004).

Rainfall is collected, concentrated and used for the irrigation of crops, pastures, trees, forlivestock consumption and household purposes. Therefore each system requires a:

- "runoff area" (catchment) with a sufficiently high run-off coefficient and a
- "run-on" area for utilisation and / or storage of the accumulated water.

Major types of Water Harvesting

According to the size of the catchment and the ratio between the size of the catchment and that of the cropping area, two major types of water harvesting (WH) for agricultural purposes are distinguished: Rainwater Harvesting and Floodwater Harvesting. The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield. Water collected from roofs and paved courtyards is mainly used for domestic purposes, very rarely for garden crops, too. There are two major groups of techniques of Rainwater Harvesting:

- **Microcatchment water harvesting** is a method of collecting surface runoff (sheet or rill flow) from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a single tree or bush or with annual crops (Prinz 2001).
- **Macrocatchment water harvesting** is also called "water harvesting from long slopes" or "harvesting from external catchment systems" (Pacey & Cullis 1988). In this case, the runoff from hillslope catchments is conveyed to the cropping area, which is located below the hillfoot on flat terrain.

The eight water harvesting techniques presented in Figure1 are not the only water harvesting systems known but they do represent the major range of techniques for different situations and productive uses. In a number of cases, the system which is described here is the most typical example of a technique for which a number of variations exist - trapezoidal bunds are a case in point.

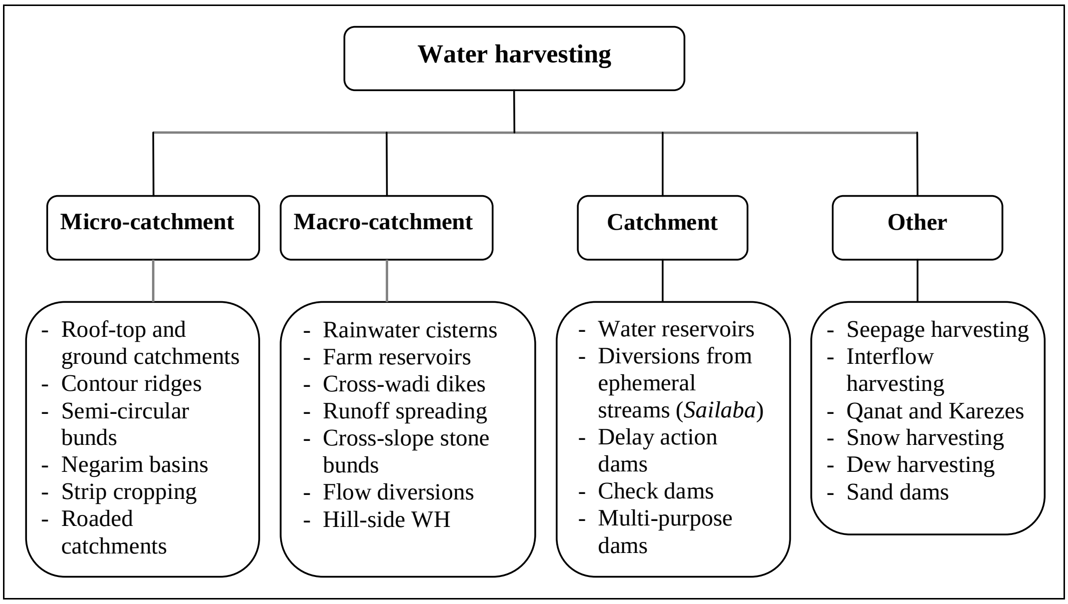

Figure 1. Main Water Harvesting Systems

Emerging Trends in Water Harvesting

Limited freshwater resources and burgeoning demand for food production have increased the demand of water harvesting in arid and semi-arid regions. To be sustainable, the water harvesting faces two-fold challenges.

- Developing possible ways and means that ensure sustainable water harvesting vis-à-vis maximize its productive use. The development should have either no or low/mitigable negative impacts.
- The developed water harvesting system must be in tune with the existing agro-ecological and socio-economic conditions.

A sustainable water harvesting system should not negatively affect the hydrological cycle capacity of a system. Reduction in groundwater recharge and drying out of Qanat and Karezes (sub-surface flow channels) in many dry areas could be result of disproportionate water harvesting at upstream (Author’s experience in Syria and Pakistan). To meet these challenges one needs to adopt a systems approach based on water, sediment and nutrients balance and dealing with the initial negative returns that many water harvesting systems, particularly, raising fruit trees and range rehabilitation, face. Further, many water harvesting systems (catchment and other in Fig. 1) that did not get due attention in the past, should be incorporated in developmental research in future. These systems have great improvement potential as well as challenges. Water harvesting, now-a-days, is seen expanding from domestic to regional and national levels and from micro-catchment to basin scales. In the future, water harvesting for flood mitigation, environmental management (reduced land degradation, dilution and eco-system management), streams restoration, groundwater recharge and for other developmental purposes will be on board. These emerging trends in water harvesting call for a comprehensive definition that encompasses all these elements. A new definition, "*Water harvesting is a process of concentrating, capturing, storing and regulating the run-on, runoff, inter- or stream flows for in-situ, on-site or off-site uses for conservative and/or sustainable developmental purposes*", is proposed. This is a broad-based definition, which also reflects "water use" as a rationale for water harvesting. The concepts of sustainable contemporary water harvesting can thus be built on this definition by considering demand- and supply- sides as an integral part of the system.

Numerous water harvesting projects have failed because the technology used proved to be unsuitable for the specific conditions of the site (Siegert 1994). Each of the water harvesting methods has its advantages and limitations which can be summarized as follows:

(1) Water harvesting for animal consumption

In developing countries, the building or reactivation of cisterns and other rainwater tanks for animal consumption can save water which othewise has to be lifted or pumped from groundwater or carried over long distances.

In "developed" countries (the USA, Australia) the search for cheap, durable soil treatment substances (e.g. sodium methyl silanolate) or ground covers continues (Arar 1993). It is expected that the costs for such treatments will be low enough in the future to treat larger areas and to obtain toxic-free runoff water.

(2) Inter-row water harvesting

In regions with not less than 200 mm (winter-rains) to 300 mm (summer-rains) annual precipitation, interrow water harvesting will have a high potential in low-income as well as in high-income countries. Contour ridges or bunds can be formed using hand tools, animal-drawn equipment or tractors, and therefore this technique is widely applicable for use in orchard establishment, general tree planting or for the cultivation of annual crops. Under high-input conditions (e.g. in the USA), the space between the rows is often compacted and chemically treated to increase runoff.

(3) Microcatchment systems

Most of the research on microcatchment development has been done in Israel. A cost/benefit analysis carried out on negarin-type microcatchments in Israel in an area with less than 150 mm annual rainfall showed however, that the specific water supply was not sufficient for economic production (Oron et al. 1983). In this case, larger forms of Negarin microcatchment in higher rainfall areas seem to be more appropriate. The various other microcatchment types have their specific advantages. The quickest way to produce microcatchments is with the 'Dolphin' plough, being able to 'dig' 5000 microbasins per day, equivalent to a treated surface of 10 ha, with a water holding capacity of 600l/basin (Antinori and Vallerani 1994).

(4) Medium-sized catchment water harvesting. Medium-sized and microcatchment systems are regarded to have a high potential in the future. The desertification processes in many (semi-) arid regions have created large denuded surfaces, which are extremely difficult to revegetate. These surfaces often yield high quantities of runoff water, which could be utilized with MSC-WH systems, especially with 'hillside conduit systems'. Many problems were experienced with trapezoidal bunds; "liman" terraces worked well in the past, if hydrologically calculated correctly, and will be a positive asset for future development (re-vegetation) in pre-desert regions.

(5) Large catchment water harvesting systems. If the development of those area systems can be combined with flood protection works for ephemeral streams, then a limited increase can be forecasted.

Micro-catchment Water Harvesting (MCWH)

MCWH is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin with plant (Boers and Ben-Asher, 1982). Frasier *et al.* (1979) describe that water yields of operational water-harvesting catchments usually related to the water yields measured at small-instrumented plots. Size of catchment has bearing on the yield of runoff. Under the same hydrological conditions, small area may generate runoff up to 50% of rainfall as compared with river basin where runoff may remain only 5% of the rainfall (Stern 1979). The higher runoff generation per unit area from a small catchment forms the basis of micro-catchment water harvesting as an alternative option.

Some common types of MCWH structures include continuous and intermittent contour ridges, semi-circular bunds, contour strips and Negarim basins. Small earthen or stone-made structures are constructed across the land slope along the contour. Construction along the contour ensures smooth water spreading. Land slopes between 2% and 8% are considered suitable for MCWH. Nevertheless, these structures have been constructed on flat lands and slopes up to 20%. Excavation in slope to the pit or location of plant—generally in centre of the micro-catchment, can develop a micro-catchment on flat land. Rectangular or hexagonal shapes are suitable for this purpose. Frequent damages and high maintenance cost are main implications of development of MCWH on steep slopes.

The performance of a micro-catchment depends on many factors including rainfall, soil and crop genotype. The design of micro-catchment area is important as it is responsible for adequate water supply on one side and it affects plant density (number of plants per unit area) on the other side.

Micro-catchment water harvesting (MCWH) requires development of small structures across mild land slopes, which capture overlandflow and store it in soil profile for subsequent plan tuses. Water availability to plants depends on the micro-catchment runoff yield and water storage capacity of both the plant basin and the soil profile in the plant rootzone. This study assessed the MCWH potential of a Mediterranean arid environment in Syria by using runoff micro-catchment and soilwater balance approaches (Akhtar et al., 2010). Average annual rainfall and evapotranspiration of the studied environment were estimatedas 111 and 1671 mm, respectively. This environment hardly supports vegetation without supplementary water. During the study period, the annual rain was158 mm in year 2004/2005, 45 mm in year 2005/2006 and 127 mm in year 2006/2007. About 5000 MCWH basins were developed for shrub raising on a land slope between 2 and5 % by using three different techniques. Runoff at the outlets of 26 micro-catchments with catchment areas between 13 and 50m^2 was measured. Also the runoff was indirectly assessed for another 40 micro-catchments by using soil water balance in the micro-catchments and the plant basins. Results show that runoff yield varied between 5 and 187m^3 ha^{-1} for various rainfall events. It was between 5 and 85% of the incidental rainfall with an average value of 30 %. The rainfall threshold for runoff generation was estimated about 4mm. Overall; the soil water balance approach predicted 38–57 % less water than micro-catchment runoff approach. This difference was due to the reason that the micro-catchment runoff approach accounted for entire event runoff in the tanks;thus showed a maximum water harvesting potential of the micro- catchments. The different between maximum water harvesting potential and soil-water storage capacity is surplus runoff that can be beter utilized through appropriate MCWH planning.

The performance of a small runoff-basin water-harvesting system (negarim) was evaluated under an arid environment in Southeastern Anatolia region of Turkey. The Tektek Water Conservation research station is located 50 km east of Şanlıurfa (37° 07’ 30’’N and 39° 15’ 00’’E; 530 m a.s.l). Average annual rainfall is 371 mm. Rainfall, runoff, catchment area, soil water storage, and crop evapotranspiration were analyzed as elements of one system. One micro-catchment area (36 m^2) and four surface treatment methods (hay covered, stone covered, plastic covered, and compaction) were used. Runoff efficiency was evaluated for the rainfall events occurred during the growth period of pistachio. Storage efficiency was evaluated for the season by monitoring soil water balance in the crop root zone. The overall efficiency of the water-harvesting system was determined as the ratio of the amount of water stored and used by the crop to the amount of rainfall received in the catchment area. The overall efficiency of the system varied from over 79% to as low as 2.6% depending on the treatment of the catchment area and the root zone capacity. Gains in runoff improvement were lost when the soil moisture in the cultivated area was near field capacity.

Surface treatments had significant effect on plant height and stem diameter. Plant heights were in order order of plastic cover (158 cm), followed by surface compaction (128 cm); and hay cover (121 cm), stone cover (117 cm) and control (102 cm). Among the surface treatments stone cover was the least effective on the other hand plastic cover was superior to other treatments on plant height. Plastic cover had significantly different effect on stem diameter than other treatments. Plastic cover resulted in stem circumference of 42 cm, stone cover had 26.2 cm, surface compaction had 30.1 cm, hay cover had 28.1 cm ve control 25.5 cm.

Table 1. Some physical properties of the experimental soil

Soil depth (cm)	Soil fraction			Soil Texture	Saturation Water Content (%)	Bulk Density (g/cm^3)	% Pw	
	sand (%)	clay (%)	silt (%)				FC (g/g)	PWP g/g
0 - 30	35.68	39.04	25.28	Clay-loam	58	1.26	28.91	19.27
30 - 60	37.68	41.04	21.28	CL	51	1.25	28.54	19.02
60 - 90	43.68	35.04	21.28	Loam	44	1.26	27.39	18.26

Table 2. Some chemical properties of the experimental soil

Soil depth (cm)	pH	Salt dS/m	$CaCO_3$ (%)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Total N (N) (%)	Organic matter (%)
0 - 30	7.70*	2.85	30.00	21.2	1231	0.11	2.24
30 - 60	7.74**	3.22	30.40	13.5	518	0.11	2.18
60 - 90	7.85***	1.24	29.60	21.7	410	0.09	1.88

Experimental soil has clay-loam texture in the top 60 cm layer,anf 60-90 cm layer is loam textured. Slope of the experimental area varies between 5 to 8%. Layout of negarim micro-catchment and its dimentions are shown in Figure 2.

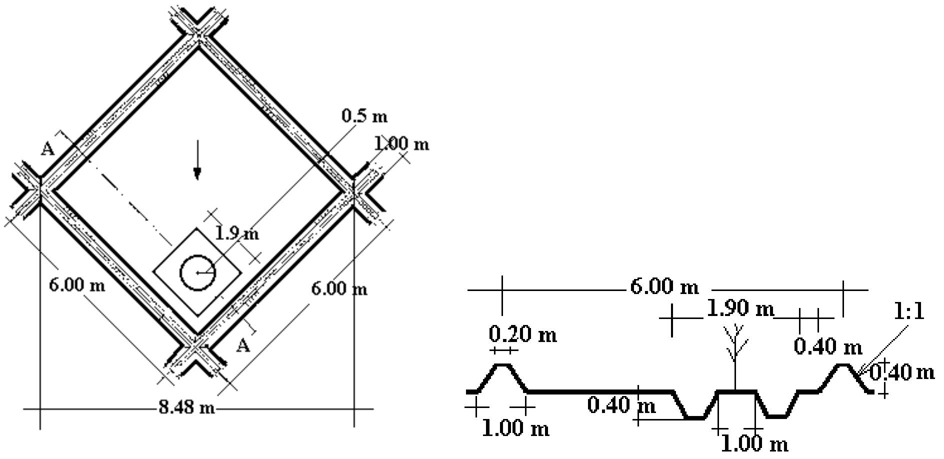

Figure 2. Layout of negarim microcatchment and its cross section.

Runoff produced by the different ground cover in negarim plots during the growing season of 2011 is shown in Figures 3 and 4.

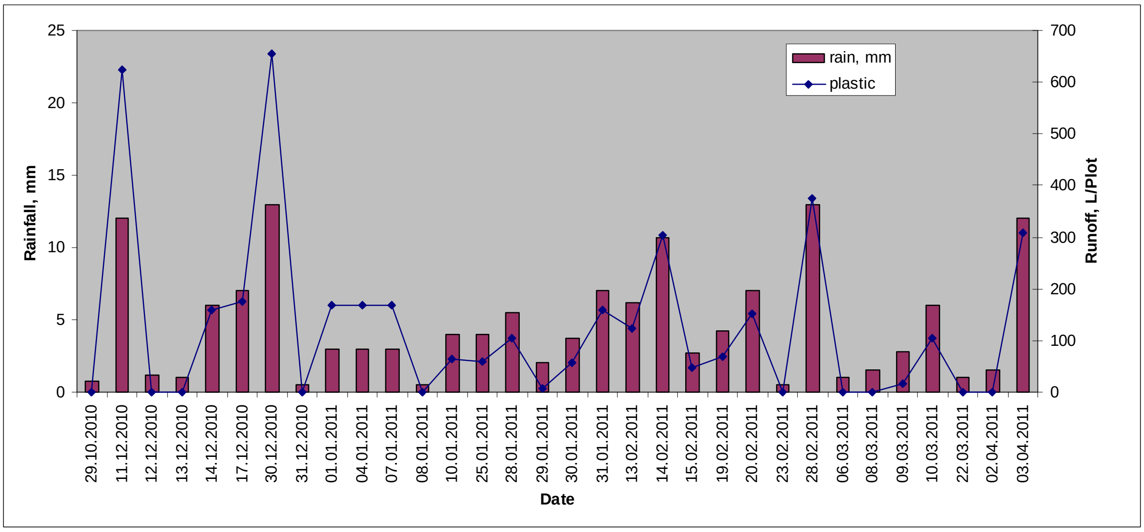

Figure 3. Runoff produced by the different ground cover in negarim plots during the growing season of 2011.

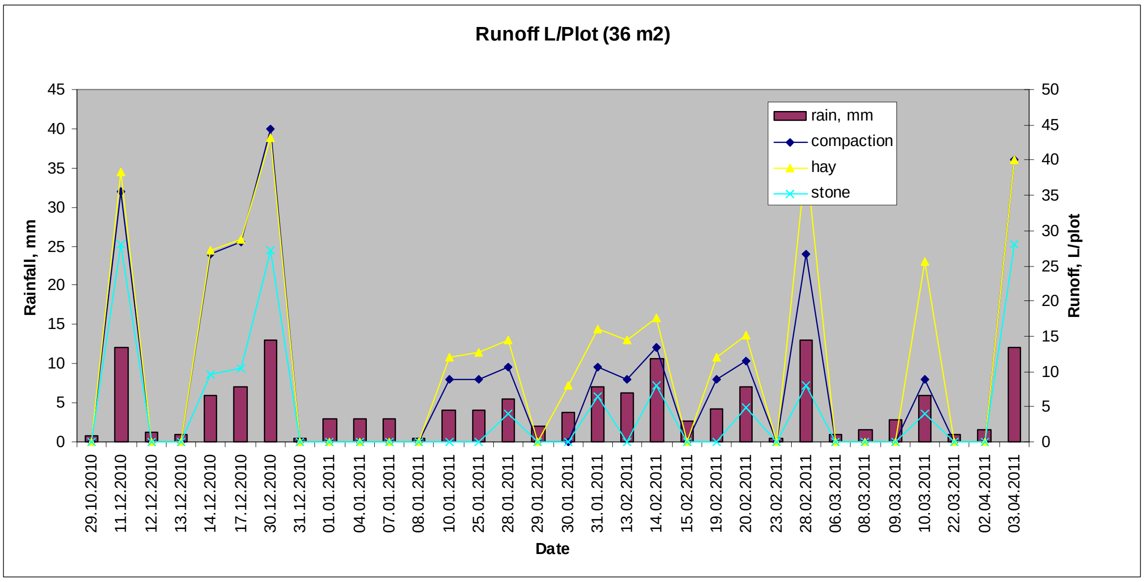

Figure 4. Runoff produced by the different ground cover in negarim plots during the growing season of 2011.

The establishment of small earthen dikes, in a v-shape or semi-circle just down-slope of the tree, allows the harvesting of a critical water supplement for olive production in water-scarce environments. To provide recommendations for the development of farmer-based microcatchment water-harvesting systems, research was conducted in a recently established (1999), untilled olive orchard on the limestone hill slopes of Khanasser Valley, Syria (Bruggeman et al., 2004). Long-term average winter rainfall in the valley is low (210 mm), but events that produce runoff on these stony slopes occur regularly. Small and large microcatchments (50 and 70 m2) were established on 8% slopes (S8 and L8) and 50-m2 catchments on 15% slopes (S15). Soil moisture measurements were taken with a neutron probe in the tree basin and in the catchment area every week during the rain season. The average amount of water harvested during the wet 2002/03 season (302 mm) was 121 L for L8, 140 L for S15, and 150 L for S8. The benefits of water harvesting for these young trees were reduced by the limited depths of the soil profile (45-120 cm). The research activities and discussions with olive growers in the valley have motivated a number of farmers to apply water harvesting techniques in both tilled and untilled orchards on the slopes.

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